Sand Filters

Chapter 8

8.1 Introduction

Sand filters operate in a similar manner to bioretention systems, with the exception that stormwater passes through a filter media (typically sand) that has no vegetation growing on the surface. Sand filters do not incorporate vegetation because the filter media does not retain sufficient moisture to support plant growth and they are often installed underground (therefore light limits plant growth). The absence of vegetation and the associated biologically active soil layer typically created around the root zone of vegetation planted in bioretention systems, means sand filters have a reduced stormwater treatment performance compared to bioretention systems.

Sand filters should only be considered where site conditions, such as space or drainage grades, limit the use of bioretention systems. This is most likely related to retrofit situations where the surrounding urban environment is already developed. Treatment can then be achieved underground with sand filters, in areas such as high density developments with little or no landscape areas. Their lack of vegetation requires more regular maintenance than bioretention systems to ensure the surface of the sand filter media remains porous and does not become clogged with accumulated sediments. This typically involves regular inspections and routine removal of fine sediments that have formed a ‘crust’ on the sand filter surface.

Prior to entering a sand filter, flows must be subjected to pre-treatment to remove litter, debris and coarse sediments (typically via an ‘inlet chamber’, which is designed as part of the system). Following pretreatment, flows are spread over the sand filtration media and water percolates downwards and is intercepted by perforated pipes located at the base of the sand media. The perforated pipes collect treated water for conveyance downstream. During higher flows, water can pond on the surface of the sand filter increasing the volume of water that can be treated. Very high flows are diverted around sand filters to protect the sand media from scour.

8.2 Design Considerations

8.2.1 Configuration

A sand filter system typically consists of three chambers: an inlet chamber that allows sedimentation and removal of gross pollutants, a sand filter chamber and a high flow bypass chamber, as illustrated in Figure 8-1. The shape of a sand filter can be varied to suit site constraints and maintenance access, provided each of the chambers is adequately sized.

8.2.1.1 Sedimentation Chamber

Water firstly enters the sedimentation (inlet) chamber where gross pollutants and coarse to medium-sized sediments are retained. Stormwater enters this chamber either via a conventional side entry pit or through an underground pipe network.

The sedimentation chamber can be designed to either have permanent water between events or to drain between storm events with weep holes. There are advantages and disadvantages with each approach. The decision of which type of system is most appropriate must be made based on catchment runoff characteristics and downstream receiving environment, likely maintenance programs (and available equipment) and site accessibility.

Having a permanent water body reduces the likelihood of re-suspension of sediments at the start of subsequent rainfall events as inflows do not fall and scour collected sediments. This system requires the removal of wet material from the sedimentation chamber during maintenance, which is more costly than for drained material. However, where appropriate maintenance machinery (such as vacuum trucks) is available, these costs may be manageable. A potential issue with these systems arises from the stagnant water and potentially high organic loads that can lead to anaerobic conditions. This may cause the release of soluble pollutants (such as phosphorus) and generation of odorous gases. This transformation of particulate bound pollutants to soluble forms can lead to a reduced treatment performance by the sand filter as soluble forms of nutrients and metals are more difficult to retain and process within the sand filtration chamber. The subsequent discharge of soluble forms of pollutants can cause water quality problems downstream (such as excessive algal growth).

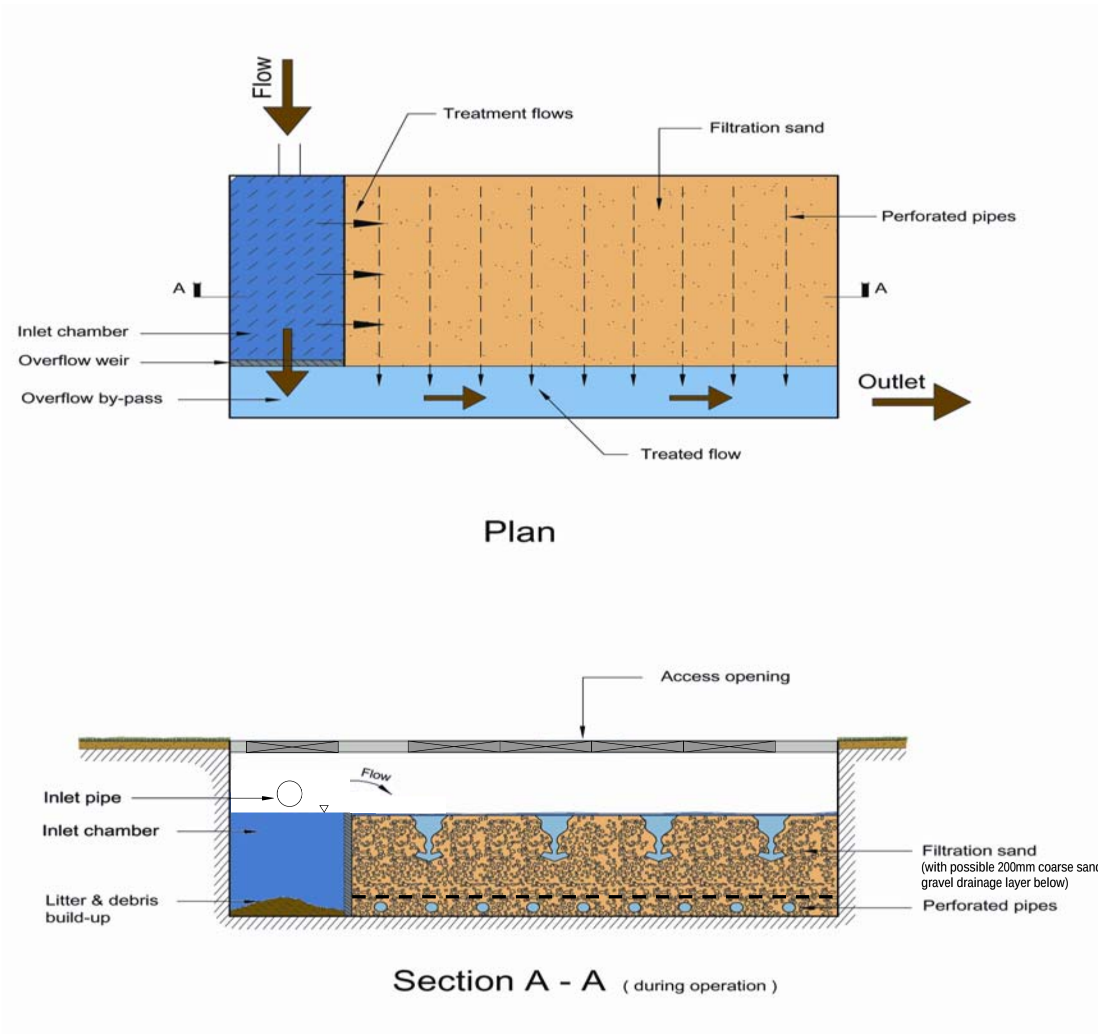


Figure 8-1: Typical Sand Filter Configuration during Operation

Allowing the sedimentation chamber to drain during inter-event periods (by the installation of weep holes) reduces the likelihood of pollutant transformation during the inter-event period. The challenge with this system is to design weep holes such that they do not block and can continue to drain as material (litter, organic material and sediment) accumulates. Drained sediment chambers are also prone to re-suspension of accumulated material as the initial flows from subsequent rainfall events enter the chamber. Where re-suspension is expected to be an issue, a baffle arrangement or other structure to manage incoming flow velocities may be constructed across the inlet flow path to minimise turbulence as flow enters the sediment chamber and thus reduce potential for re-suspension of sediments.

It should also be noted that free-draining dry chambers result in a portion of the detained stormwater (particularly low-flows) being discharged without receiving treatment by the sand filter. To reduce the amount of untreated flow from the chamber, drainage holes between the sediment chamber and the sand filter chamber can be provided to drain the sediment chamber into the sand filter media. Alternatively, additional treatment could be provided to this discharged stormwater through another treatment device (e.g. wetlands or bioretention systems).

The sedimentation chamber requires sufficient access space for manual removal of sediment and accumulated debris during maintenance operations. These factors need to be considered when designing the sedimentation chamber.

8.2.1.2 Sand Filter Chamber

Stormwater flows from the sedimentation chamber into the sand filter chamber via a weir. Water then percolates through the sand filtration media (typically 400-600 mm depth) and perforated under-drain pipes collect filtered water in a similar manner to bioretention systems. Provision for temporary ponding is provided within the sand filter chamber. When water levels reach the maximum ponding depth, flows spill over to an overflow (bypass) chamber (usually via the sedimentation chamber). The bypass chamber protects the surface of the sand filter media from scour during high flow events. The high saturated hydraulic conductivity of the sand filtration media means that only a small (~200 mm) extended detention (temporary ponding) depth is required.

The sand filter media will typically have a saturated hydraulic conductivity between 1 x 10^{-4} m/s (360 mm/hr) to 1 x 10^{-3} m/s (3600 mm/hr) depending on the selected sand particle size distribution. The material should be free of fines and have a relatively uniform grain size distribution. Example particle size distributions are provided in Section 8.3.4.1. The surface of the sand filter media should be set at the crest of the weir connecting the sedimentation chamber to the sand filter chamber. This minimises potential scouring of the sand surface as water flows into the sand filter chamber. Alternatively, where the crest of the sediment chamber weir (treatment flow weir) is elevated above the sand filter surface, appropriate scour protection must be used.

The sand filter chamber typically comprises two layers, a drainage layer consisting of a clean washed river sand with saturated hydraulic conductivity >4000 mm/hr overlain by the sand filter media described above. The drainage layer contains either flexible perforated pipes (e.g. ag pipes) or slotted PVC pipes, however care needs to be taken to ensure the slots in the pipes are not so large that particles can freely flow into the pipes from the drainage layer. The slotted or perforated collection pipes at the base of the sand filter collect treated water for conveyance downstream. They should be sized so that the filtration media freely drains and the collection system does not become a 'choke' in the system.

In some circumstances it may be desirable to restrict the discharge capacity of sand filter chamber so as to promote a longer detention period within the sand filter media and therefore allow for increased biological treatment from longer contact time. One such circumstance is when depth constraints may require a shallower filter media depth and a larger surface area, leading to a higher than desired maximum infiltration rate. In such circumstances it is recommended that the drainage layer and under drainage pipe network be designed so as to not become the hydraulic "choke" in the system (as above) and that a control valve be used at the outfall of the underdrainage system to regulate the detention time in the sand filter media. In this way greater control over detention time can be achieved.

8.2.1.3 Overflow Chamber

The overflow chamber provides a bypass during flood events to downstream drainage infrastructure. When water levels in the sedimentation and sand filter chambers exceed the extended detention depth, water overflows a weir into the bypass chamber and is conveyed into the downstream drainage system. The overflow weir is sized to ensure that it has sufficient capacity to convey the minor storm flow (typically the 2-10 year ARI).

8.2.2 Maintenance

Sand filters have no vegetation to break up the filter surface (unlike bioretention systems); therefore, maintenance is critical to ensuring continued performance, particularly in preserving the hydraulic conductivity of the filtration media. Without regular maintenance (e.g. 3-6 months with more frequent inspections to determine clean out requirements), collected fine material will create a 'crust' on the surface that significantly decreases infiltration capacity. Regular maintenance involves removing the surface layer of fine sediments that can tend to clog the filtration media.

Inspections of the sedimentation chamber need to be performed every 1-6 months (as for the sand filter chamber); however, sediment and/ or gross pollutant cleanout may only be required annually. The frequency will ultimately depend on upstream catchment activities and will be linked to seasonal rainfall (i.e. high summer rainfall may require more frequent cleanouts). Of particular importance are regular inspections during and immediately following construction and these should be conducted after the first few significant rainfall events. Records of all inspections and maintenance activities should be documented and filed for future use.

There are several key decisions during design that significantly impact on ease of maintenance for a sand filter. Easy access for maintenance is fundamental to long term performance and needs to be considered early during design. This includes both access to the site (e.g. traffic management options) as well as access to the sedimentation and sand filter chambers (including less frequent access to the overflow chamber).

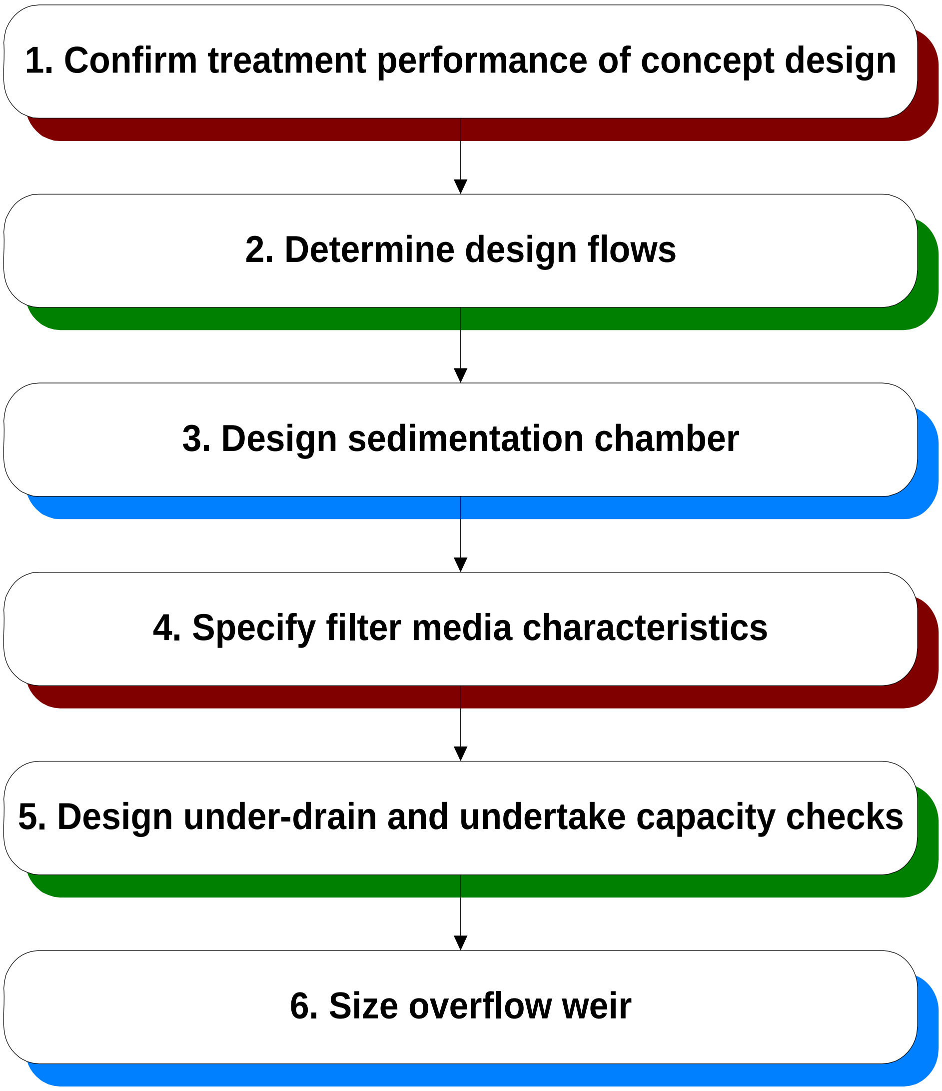
Direct physical access to the whole surface of the sand filter chamber will be required to remove fine sediments from the surface layer of the filter media (top 25-50 mm) as they accumulate forming a crust. Depending on the scale of the system, this may require multiple entry points to the chamber to enable access with a shovel or vacuum machinery. If maintenance crews cannot access part of the sand filter chamber, it will quickly become blocked and thus reduce water quality improvement.

The sedimentation chamber needs to be drained for maintenance purposes (unless appropriate wet extraction equipment is available). A drainage valve or gate should be incorporated into systems that have no weep holes so that this chamber can fully drain. Having freely drained material significantly reduces the removal and disposal maintenance costs. Alternatively, water in the sediment chamber can be pumped into the sand filter and then pollutants removed.

The perforated collection pipes at the base of the sand filter are also important maintenance considerations. Provision should be made for flushing (and downstream capture of flushed material) of any sediment build up that occurs in the pipes. This can be achieved by extending the under-drains to the surface of the sand filter to allow for inspection and maintenance when required. The vertical section of the under-drain should be either solid pipe or wrapped in impermeable geotextile and a cap placed on the end of the pipe to avoid short circuiting of flows directly in to the drain. A temporary filter sock or equivalent should also be placed over the outlet pipe in the overflow chamber to capture flushed sediment during maintenance activities.

8.3 Design Process

The following sections detail the design steps required for sand filters. Key design steps are:



8.3.1 Step 1: Confirm Treatment Performance of Concept Design

This step ensures the detailed designer of the sand filter system first checks the general dimensions and configuration of the concept design layout before proceeding to detailed design. Before commencing detailed design, the designer should first undertake a preliminary check to confirm the sand filter treatment area from the concept design is adequate to deliver the required level of stormwater quality improvement. This assessment should be undertaken by a WSUD specialist and can be achieved by modelling expected treatment performance in an appropriate quantitative modelling program. Where possible, this modelling should be based on local rainfall data, the proposed configuration of the system, and based on local stormwater treatment performance data.

It should be noted that sand filters should form part of the stormwater 'treatment train' as they will not achieve contemporary load-based objectives on their own. Therefore, other stormwater quality best management practices should be incorporated into the surrounding catchment to augment the stormwater treatment performance of any proposed sand filter system.

8.3.2 Step 2: Determine Design Flows

Three design flows are required for sand filters:

- 'Sedimentation chamber design flow' – this would normally correspond to a 1 year ARI peak discharge as standard practice for sedimentation basins.
- 'Sand filter design flow (or maximum infiltration rate)' – this is the product of the maximum infiltration rate and the surface area of the sand filter, used to determine the minimum discharge capacity of the under-drains to allow the filter media to freely drain.
- 'Sedimentation chamber above design flow' – this is for design of the weir connecting the sand filter to the overflow chamber 'spillway' to allow for bypass of high flows safely around the sand filter chamber. Defined by either:
    - Minor design flow (2 year ARI) – required for situations where only the minor drainage system is directed to the sedimentation basin. For commercial and industrial areas the design flow requirement for minor flows is a 5 year ARI event.
    - Major flood flow (50 year ARI) – required for situations where the major drainage system discharges into the sedimentation basin.

8.3.2.1 Design Flow Estimation

QUDM identifies the Rational Method as the procedure most commonly used to estimate peak flows from small catchments in Queensland. As sand filters are only recommended for small catchments (e.g. less than 10 hectares), the Rational Method is recognised as an appropriate method to use in the determination of peak design flows.

8.3.2.2 Maximum Infiltration Rate

The maximum infiltration rate represents the design flow for the under-drainage system (i.e. the slotted pipes at the base of the filter media). The capacity of the under-drains needs to be greater than the maximum infiltration rate to ensure the filter media drains freely and the pipe does not become a 'choke' in the system.

The maximum infiltration rate (Q_{max}) can be estimated by applying Darcy's equation:

$$Q_{max} = K_{sat} \cdot A \cdot \frac{h_{max} + d}{d}$$ Equation 8.1

where K_{sat} = hydraulic conductivity of the soil filter (m/s)

A = surface area of the sand filter (m^2)

h_{max} = depth of pondage above the sand filter (m)

d = depth of the filter media (m)

8.3.3 Step 3: Design Sedimentation Chamber

The dimensions of the sedimentation chamber should be sized to retain sediments larger than 125 μm for the sedimentation chamber design flow (typically 1 year ARI peak flow) and to have adequate capacity to retain settled sediment (and gross pollutants) such that the cleanout frequency is a minimum of once per year. A target sediment capture efficiency of 70 % is recommended. This is lower than would be recommended for sedimentation basins that do not form part of a sand filter (see Chapter 4). With a sand filter, lower capture efficiencies can be supported because of the maintenance regime of the filter media (inspections and either scraping or removal of the surface of the sand filter twice a year) and particle size range in the sand filter being of a similar order of magnitude as the target sediment size of 125 μm.

During storm events, stormwater in the sedimentation chamber is discharged (via surcharge) over a weir into the sand filter chamber. This weir will have a maximum discharge capacity that is equal to the sand filter design flow.

The overflow weir to the bypass channel is also typically located within the sedimentation chamber. The sizing of the overflow weir is covered in detail in Step 6 (Section 8.3.6).

It is necessary to check that deposited sediments of the target sediment size or larger are not resuspended during the passage of the design peak discharge for the overflow bypass channel. A maximum flow velocity of 0.2 m/s is recommended through the sedimentation chamber before bypass occurs and 0.5 m/s for the overflow design flow rate. Velocities are estimated by dividing the cross section area by the design flow rate.

The reader is referred to Chapter 4 for guidance on the sizing the sedimentation chamber allowing for the recommended 70 % capture efficiency for sediments.

8.3.4 Step 4: Specify the Filter Media Characteristics

Filter media in the sand filter chamber consist of two layers: (1) drainage layer consisting of clean washed river sand or gravel material to encase the perforated under-drains and (2) a sand filtration layer.

8.3.4.1 Filter media

A range of particle sizes can be used for sand filters depending on the likely size of generated sediments. Material with particle size distributions described below has been reported as being effective for stormwater treatment (ARC 2003):

% passing	9.5 mm	100 %
	6.3 mm	95-100 %
	3.17 mm	80-100 %
	1.5 mm	50-85 %
	0.8 mm	25-60 %
	0.5 mm	10-30 %
	0.25 m	2-10 %

This grading is based on TP10 (ARC 2003).

Alternatively, finer material can be used (described below), however this will require more attention to maintenance to ensure the material maintains sufficient hydraulic conductivity and does not become blocked. Inspections should be carried out every 1-6 months during the initial year of operation as well as after major storms to check for surface clogging.

% passing	1.4 mm	100 %
	1.0 mm	80 %
	0.7 mm	44 %
	0.5 mm	8.4 %

8.3.4.2 Drainage Layer

A drainage layer is used to convey treated flows from the base of the filter media layer into the perforated under-drainage system. The particle size of the drainage layer is selected with consideration of the perforated under-drainage system (refer to Section 8.3.5) as the slot sizes in the perforated pipes may determine the minimum drainage layer particle size that will not be washed into the perforated pipes. Coarser material (e.g. fine gravel) must be used for the drainage layer if the slot sizes in the perforated pipes are too large for use of a sand based drainage layer. Otherwise, a clean washed river sand is the preferred drainage layer media. The drainage layer must be a minimum of 200 mm thick.

8.3.5 Step 5: Under-drain Design and Capacity Checks

Treated water that has passed through the filtration media is directed into slotted pipes located within the 'drainage layer' or at the base of the sand filtration layer (when a drainage layer is not required). The maximum spacing of the slotted or perforated collection pipes is to be 1.5 m (centre to centre) so that the distance water needs to travel through the drainage layer does not hinder drainage of the filtration media. Installing parallel pipes is a means to increase the capacity of the collection pipe system. Collection pipes are to be a maximum of 100 mm diameter. To ensure the slotted or perforated pipes are of adequate size, several checks are required:

- Ensure the perforations (slots) are adequate to pass the maximum infiltration rate (or the maximum required outflow).
- Ensure the pipe itself has adequate capacity.

8.3.5.1 Perforations Inflow Check

To estimate the capacity of flows through the perforations, orifice flow conditions are assumed and a sharp edged orifice equation can be used. Firstly, the number and size of perforations needs to be determined (typically from manufacturer's specifications) and used to estimate the flow rate into the pipes using a head of the filtration media depth plus the ponding depth. Secondly, it is conservative but reasonable to use a blockage factor (e.g. 50 % blocked) to account for partial blockage of the perforations by the drainage layer media.

$$Q_{perf} = B \cdot C_d \cdot A_{perf} \cdot \sqrt{2 \cdot g \cdot h} \qquad \text{Equation 8.2}$$

where Q_{perf} = flow through perforations (m^3/s)

B = blockage factor (0.5-0.75)

C_d = orifice discharge coefficient (~0.6)

A = total area of the perforations (m^2)

g = gravity (9.81 m/s^2)

h = depth of water over the collection pipe (m)

The combined discharge capacity of the perforations in the collection pipe(s) must exceed the design discharge of the sand filter unless the specific intention is to increase detention time in the sand filter by limiting the discharge through the collection pipe.

8.3.5.2 Perforated Pipe Capacity

The discharge capacity of the collection pipe (Q_{pipe}) can be calculated using an orifice flow equation similar to that expressed in Equation 8.2, assuming that the pipe has no blockage restricting the flow (i.e. B = 1). This equation is used in preference to Manning's equation, as the pipe is completely submerged while discharging.

$$Q_{pipe} = C_d \cdot A_{pipe} \sqrt{2 \cdot g \cdot h}$$ Equation 8.3

where Q_{pipe} = flow through pipe(s) (m^3/s)

C_d = orifice discharge coefficient (~0.6)

A = area of the pipe(s) (m^2)

g = gravity (9.81 m/s^2)

h = depth of water over the collection pipe (m)

The capacity of this pipe must exceed the maximum infiltration rate.

8.3.6 Step 6: Size Overflow Weir

The overflow weir is typically located in the sedimentation chamber. The overflow weir must be sized to ensure that it has sufficient capacity to convey the design discharge from the sedimentation chamber (typically 2 year ARI peak flow).

When water levels in the sedimentation and sand filter chambers exceed the extended detention depth, water will overflow directly from the sedimentation chamber (bypassing the sand filter) into the overflow/ bypass chamber and be conveyed into the downstream drainage system. Water levels in the overflow chamber must remain below ground when operating at the design discharge for the minor stormwater drainage system.

A broad crested weir equation can be used to determine the length of the overflow weir:

$$Q_{weir} = C_w \cdot L \cdot h^{3/2}$$ Equation 8.4

where Q_{weir} = flow rate over weir (m^3/s)

C_w = weir coefficient (~1.7)

L = length of the weir (m)

h = depth of water above the weir (m)

8.3.7 Design Calculation Summary

Below is a design calculation summary sheet for key design elements of sand filters to aid the design process.

SAND FILTER DESIGN CALCULATION SUMMARY

	Calculation Task		CALCULATION SUMMARY Outcome	Check
	Catchment Characteristics			
		Catchment area	Ha	
		Catchment landuse (i.e. residential, commercial etc.)		
		Storm event entering inlet	yr ARI	
	Conceptual Design			
		Sand filter area	m^2	
		Filter media saturated hydraulic conductivity	mm/hr	
		Extended detention depth	mm	
1	Verify size for treatment			
		Sand filter area to achieve water quality objectives		
		Total suspended solids	% of catchment	
		Total phosphorus	% of catchment	
		Total nitrogen	% of catchment	
		Sand filter area	m^2	
		Extended detention depth	m	
2	Determine design flows			
		'Sedimentation chamber design flow' (1 year ARI)	year ARI	
		'Sedimentation chamber above design flow' (2 to 50 year ARI)	year ARI	
	Time of concentration		minutes	
	(Refer to Townsville City Development Guidelines/ QUDM) Identify rainfall intensities			
		'Sedimentation chamber design flow' - $I_{1\ year\ ARI}$	mm/hr	
		'Sedimentation chamber above design flow' - $I_{2\ year\ ARI}$ to $I_{50\ year\ ARI}$	mm/hr	
	Design runoff coefficient			
		'Sedimentation chamber design flow' - $C_{1\ year\ ARI}$		
		'Sedimentation chamber above design flow' - $I_{2\ year\ ARI}$ to $I_{50\ year\ ARI}$		
	Peak design flows			
		'Sedimentation chamber design flow' - 1 year ARI	m^3/s	
		'Sedimentation chamber above design flow' – 2 to 50 year ARI	m^3/s	
		Q_{max}	m^3/s	
3	Design sedimentation chamber			
		Required surface area?	m^2	
		length x width	m	
		depth	m	
		Design particle size	mm	
		CHECK SCOUR VELOCITY (<0.5 m/s)?	m/s	
		CHECK OVERFLOW CAPACITY?	m^3/s	
4	Specify sand filter media characteristics			
		Filter media hydraulic conductivity	mm/hr	
		Filter media depth	mm	
		Drainage layer depth	mm	
		Provided specification for sand media?		
5	Under-drain design and capacity checks			
		Flow capacity of filter media	m^3/s	

SAND FILTER DESIGN CALCULATION SUMMARY					
			CALCULATION SUMMARY		
	Calculation Task		Outcome		Check
	Perforations inflow check				
		Pipe diameter		mm	
		Number of pipes			
		Capacity of perforations		m^3/s	
		CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY			
	Perforated pipe capacity				
		Pipe capacity		m^3/s	
		CHECK PIPE CAPACITY > FILTER MEDIA CAPACITY			
6	Size overflow weir				
		Design storm for overflow (e.g. 2yr ARI)			
		weir length		m	

8.4 Construction Advice

This section provides general advice for the construction of sand filters. It is based on observations from construction projects around Australia.

8.4.1 Building Phase Damage

Protection of sand filtration media is very important during the building phase; uncontrolled building site runoff is likely to cause excessive sedimentation, introduce debris and litter, and could cause clogging of the sand media. Upstream measures should be employed to control building site runoff. If a sand filter is not protected during the building phase, it is likely to require replacement of the sand filter media. A recommended approach during the building phase is to “block” the weir between the sedimentation chamber and the sand filter chamber so that only the sedimentation chamber is engaged by stormwater flows. Once building is complete and the catchment is stabilised the weir can be re-opened to allow stormwater flows into the sand filter chamber.

8.4.2 Sediment Basin Drainage

When a sediment chamber is designed to drain between storms (so that pollutants are stored in a drained state), blockage of the weep holes can be avoided by constructing a protective sleeve (to protect the holes from debris blockage, e.g. 5 mm screen) around small holes at the base of the bypass weir. It can also be achieved with a vertical slotted PVC pipe, with protection from impact and an inspection opening at the surface to check for sediment accumulation. The weep holes should be sized so that they only pass small flows (e.g. 10-15 mm diameter).

8.4.3 Inspection Openings (flushing points) for Perforated Pipes

It is good design practice to have inspection openings (flushing points) at the ends of the perforated pipes. This allows for inspection of sediment build within the under-drainage system and when required an easy access point for flushing out accumulated sediments. Sediment controls downstream should be used when flushing out sediments from the under drainage system to prevent sediments reaching downstream waterways.

8.4.4 Clean Filter Media

It is essential to ensure drainage media is washed prior to placement to remove fines and prevent premature clogging of the system.

8.5 Maintenance Requirements

Maintenance of sand filters is primarily concerned with:

- Regular inspections (1-6 monthly) to inspect the sedimentation chamber and the sand filter media surface, particularly immediately after construction.
- Checking for blockage and clogging.
- Removal of accumulated sediments, litter and debris from the sedimentation chamber.
- Checking to ensure the weep holes (if provided) and overflow weirs are not blocked.

Maintaining the flow through a sand filter relies on regular inspection and removal of the top layer of accumulated sediment. Inspections should be conducted after the first few significant rainfall events following installation and then at least every six months following. The inspections will help to determine the long term cleaning frequency for the sedimentation chamber and the surface of the sand media.

Removing fine sediment from the surface of the sand media can typically be performed with a flat bottomed shovel. Tilling below this surface layer can also maintain infiltration rates. Access is required to the complete surface area of the sand filter and this needs to be considered during design.

Sediment accumulation in the sedimentation chamber needs to be monitored. Depending on catchment activities (e.g. building phase), sediment deposition can overwhelm the chamber and reduce flow capacities.

Debris removal is an ongoing maintenance function. If not removed, debris can block inlets or outlets, and be unsightly if located in a visible location. Inspection and removal of debris/ litter should be carried out regularly.

8.6 Checking Tools

This section provides a number of checking tools for designers and Council development assessment officers. In addition, Section 8.4 provides general advice on the construction of sand filters and key issues to be considered to ensure their successful establishment and operation based on observations from construction projects around Australia.

The following checking tools are provided:

- Design Assessment Checklist
- Construction Inspection Checklist (during and post)
- Operation and Maintenance Inspection Form
- Asset Transfer Checklist (following "on-maintenance" period).

8.6.1 Design Assessment Checklist

The checklist on page 8-19 presents the key design features to be reviewed when assessing the design of a sand filter. These considerations include configuration, safety, maintenance and operational issues that need to be addressed during the design phase. If an item receives an 'N' when reviewing the design, referral is made to the design procedure to determine the impact of the omission or error.

In addition to the checklist, a proposed design is to have all necessary permits for its installations. Council development assessment officers will require that all relevant permits are in place prior to accepting a design.

8.6.2 Construction Checklist

The checklist on page 8-20 presents the key items to be reviewed when inspecting the sand filter during and at the completion of construction. The checklist is to be used by construction site supervisors and compliance inspectors from Townsville City Council to ensure all the elements of the sand filter have been constructed in accordance with the design. If an item receives an 'N' in Satisfactory criteria, appropriate actions must be specified and delivered to rectify the construction issues before inspection sign-off is given.

8.6.3 Operation and Maintenance Inspection Form

The form on page 8-21 should be used whenever an inspection is conducted and kept as a record on the asset condition and quantity of removed pollutants over time.

8.6.4 Asset transfer checklist

Land ownership and asset ownership are key considerations prior to construction of a stormwater treatment device. A proposed design is to clearly identify the ultimate asset owner and who is responsible for its maintenance. The local government authority will use the asset transfer checklist on page 8-22 below when the asset is to be transferred to them.

SAND FILTER DESIGN ASSESSMENT CHECKLIST		
Sand Filter Location:		
Hydraulics:	Minor Flood (m^3/s):	Major Flood (m^3/s):
Area:	Catchment Area (ha)::	Sand Filter Area (m^2):

TREATMENT	Y	N
Treatment performance verified using MUSIC?		
INLET ZONE/HYDRAULICS	Y	N
Station selected for IFD appropriate for location?		
Configuration of sediment chamber (aspect, depth and flows) allows settling of particles >125 μm?		
Sediment chamber capacity sufficient for desilting period >=1 year?		
Scour protection provided at inlet?		
Maintenance access allowed for sediment chamber?		
Public access to system prevented?		
Drainage facilities for sediment chamber provided?		
Overall flow conveyance system sufficient for design flood event?		
Velocities at inlet and within sand filter will not cause scour?		
Bypass sufficient for conveyance of design flood event?		
COLLECTION SYSTEM	Y	N
Slotted pipe capacity > infiltration capacity of filter media (where appropriate)?		
Maximum spacing of collection pipes <1.5 m?		
Drainage layer >200 mm?		
Transition layer provided to prevent clogging of drainage layer?		
FILTER BASIN	Y	N
Maximum ponding depth will not impact on public safety?		
Collection pipes extended to surface of sand to allow inspection and flushing?		
Selected filter media hydraulic conductivity > 10 x hydraulic conductivity of surrounding soil? if not, impermeable liner provided?		
Maintenance access provided to base of filter media (where reach to any part of a basin >6 m)?		
Sand media specification included in design?		
COMMENTS		

SAND FILTER CONSTRUCTION INSPECTION CHECKLIST

Site:		Inspected by:	
		Date:	
		Time:	
Constructed by:		Weather:	
		Contact during visit:	

Items inspected	Checked		Satisfactory		Items inspected	Checked		Satisfactory	
	Y	N	Y	N		Y	N	Y	N
DURING CONSTRUCTION									
A. Preliminary works					C. Sedimentation Chamber				
1. Erosion and sediment control plan adopted					12. Invert level correct				
2. Temporary traffic/safety control measures					13. Ability to freely drain (weep holes)				
3. Location same as plans					D. Structural Components				
4. Site protection from existing flows					14. Location and levels of pits as designed				
B. Earthworks					15. Safety protection provided				
5. Level bed					16. Pipe joints and connections as designed				
6. Side slopes are stable					17. Concrete and reinforcement as designed				
7. Provision of liner (if required)					18. Inlets appropriately installed				
8. Perforated pipe installed as designed					E. Filtration System				
9. Drainage layer media as designed					19. Provision of liner				
10. Sand media specifications checked					20. Adequate maintenance access				
11. Adequate maintenance access					21. Inlet and outlet as designed				
FINAL INSPECTION									
1. Confirm levels of inlets and outlets					7. No surface clogging				
2. Traffic control in place					8. Maintenance access provided				
3. Confirm structural element sizes					9. Construction generated sediment removed				
4. Sand filter media as specified					10. Provision of removed sediment drainage area				
5. Sedimentation chamber freely drains					11. Evidence of litter or excessive debris				
6. Check for uneven settling of sand									

COMMENTS ON INSPECTION

ACTIONS REQUIRED
1.
2.
3.
4.
5.
Inspection officer signature:

SAND FILTER MAINTENANCE CHECKLIST			
Inspection Frequency:	1-6 monthly	Date of Visit:	
Location:			
Description:			
Site Visit by:			

INSPECTION ITEMS	Y	N	ACTION REQUIRED (DETAILS)
Litter within filter area?			
Scour present within sediment chamber or filter?			
Sediment requires removal (record depth, remove if >50%)?			
All structures in satisfactory condition (pits, pipes etc)?			
Traffic damage evident?			
Evidence of dumping (e.g. building waste)?			
Clogging of drainage weep holes or outlet?			
Evidence of ponding (in sedimentation chamber or sand filter)?			
Damage/vandalism to structures present?			
Surface clogging visible?			
Drainage system inspected?			
Removal of fine sediment required?			

COMMENTS

ASSET TRANSFER CHECKLIST		
Asset Description:		
Asset ID:		
Asset Location:		
Construction by:		
Defects and Liability Period:		
TREATMENT	Y	N
System appears to be working as designed visually?		
MAINTENANCE	Y	N
Maintenance plans provided for each asset?		
Inspection and maintenance undertaken as per maintenance plan?		
Inspection and maintenance forms provided?		
Asset inspected for defects?		
ASSET INFORMATION	Y	N
Design Assessment Checklist provided?		
As constructed plans provided?		
Copies of all required permits (both construction and operational) submitted?		
Proprietary information provided (if applicable)?		
Digital files (eg drawings, survey, models) provided?		
Asset listed on asset register or database?		
COMMENTS		

8.7 Sand Filter Worked Example

A concrete encased sand filter system is proposed to treat stormwater runoff from a courtyard/ plaza area along the coastal strip of Townsville. The site is nested amongst a number of buildings and is to be fully paved as a multi-purpose courtyard. Limited space is available for treatment on the site and it was determined during the concept design phase to partially treat the stormwater in a sand filter system before flows are then directed for further treatment downstream of the development, to ensure that best practice pollutant reduction is achieved. Stormwater runoff from the surrounding building is to be directed to bioretention planter boxes while runoff from this 3500 m^2 courtyard will be directed into an underground sand filter. Provision for overflow from the sand filter into the underground piped drainage system ensures that the site is not subjected to flood inundation for storm events up to the 50 year ARI. The existing stormwater drainage system has sufficient capacity to accommodate the 50 year ARI peak discharge from this relatively small catchment.

Key functions of the sand filter include the following:

- promote the capture of gross pollutants,
- promote sedimentation of 70 % of particles larger than 125 μm within the inlet zone for flows up to a 1 year ARI peak discharge,
- promote filtration of stormwater following sedimentation pre-treatment through a sand layer,
- provide for high flow bypass operation by configuring and designing the bypass chamber.

The concept design suggests that the sand filter system will remove 63 %, 36 % and 27 % of TSS, TP and TN respectively. Therefore additional treatment will be required downstream of the sand filter in order to meet best practice pollutant load reduction discharge standards. The concept design has suggested a required area of the sand filter chamber is 30 m^2, depth of the sand filter 600 mm, saturated hydraulic conductivity of 3600mm/hr and extended detention depth of 0.2 m. Larger sand filter treatment areas did not provide any additional treatment benefits when assessed using quantitative models. Outflows from the sand filter are conveyed into a stormwater pipe for discharge into existing stormwater infrastructure (legal point of discharge) via a third chamber (overflow chamber). Flows in excess of the 0.2 m extended detention depth would overflow and discharge into the underground stormwater pipe and bypass the sand filter.

<u>Design Objectives</u>

Design objectives include the following:

- Sand filter to consist of three chambers: a sedimentation (and gross pollutant trapping) chamber, a sand filter chamber and an overflow chamber.
- The sedimentation chamber will be designed to capture particles larger than 125 μm for flows up to the peak 1 year ARI design flow with a capture efficiency of 70 %. Flows up to the Maximum Infiltration Rate through the sand filter will be conveyed from the sedimentation chamber to the sand filter chamber by a series of “slot” weirs.
- Perforated sub-soil drainage pipes are to be provided at the base of the sand filter and will need to be sized to ensure the peak flow associated with the Maximum Infiltration Rate through the sand filter media can enter the pipes and that the pipes have sufficient conveyance capacity.
- The overflow weir (located in the sedimentation chamber) and the overflow chamber will be designed to receive and convey flows up to the 50 year ARI peak discharge (i.e. the Major Storm).
- The sedimentation chamber will retain sediment and gross pollutants in a dry state and have sufficient storage capacity to limit sediment cleanout frequency to once a year.
- Inlet/ outlet pipes to be sized to convey the 50 year ARI peak discharge.

Site Characteristics

The site characteristics are summarised as follows:

- catchment area — 3,500 m^2 (70 m x 50 m)
- land use/ surface type — paved courtyard
- fraction impervious — 0.90
- overland flow travel path — 50 m
- overland flow slope — 6.0 %

8.7.1 Step 1: Confirm Treatment Performance of Concept Design

The nominated area of the sand filter from the conceptual design is 30 m^2 (i.e. approx 1% of contributing catchment area). This treatment area is checked using a quantitative treatment performance model to ensure that stormwater discharges from the site comply with the relevant water quality objectives (WQOs). It is noted that subsequent additional treatment elements will be required (e.g. wetlands or bioretention systems) in order to enable such WQO compliance.

8.7.2 Step 2: Estimating Design Flows

With a small catchment (in this case 3,500 m^2), the Rational Method is considered an appropriate approach to estimate the design storm peak flow rates. The steps in this calculation follow below.

Time of Concentration (t_c)

Approach:

The time of concentration is estimated assuming overland flow across the paved courtyard. From procedures documented in QUDM (DNRW, IPWEA & BCC 1998) and the local Council's development guidelines, the overland sheet flow component should be limited to 50 m in length and determined using the Kinematic Wave Equation:

$$t = 6.94\,(L.n^*)^{0.6}/I^{0.4}\,S^{0.3}$$

where:
- t = overland sheet flow travel time (mins)
- L = overland sheet flow path length (m)
- n* = surface roughness/retardance coefficient
- I = rainfall intensity (mm/hr)
- S = slope of surface (m/m)

In urban areas, QUDM notes that sheet flow will typically be between 20 to 50 m, after which the flow will become concentrated against fences, gardens or walls or intercepted by minor channel or piped drainage (DNRW, IPWEA & BCC 1998). Therefore when calculating remaining overland flow travel times, it is recommended that stream velocities in Table 4.06.5 of QUDM be used.

Assuming:
- Predominant slope = 6%
- Overland sheet flow = 50m
- Flow path is predominately paved, with a typical n* = 0.013 (QUDM)

10 year ARI:

$$t_{sheet\ flow} = 6.94\,(50 \times 0.013)^{0.6}/(I^{0.4} \times 0.06^{0.3})$$

$$= < 5 \text{ mins}$$

Therefore adopt a 5 minute time of concentration in line with the local Council's guidelines. Iterations will usually need to be repeated until $t_{sheet\ flow}$ matches 10 year ARI rainfall intensity on the IFD chart for that duration. However in this case the time of concentration is very low for all ARIs, and therefore a 5 minute time of concentration is adopted for all design events. Note that IFD data will need to be determined in accordance with the local Council's development guidelines.

Design Runoff Coefficient

Runoff Coefficients

C_{10} = 0.88

	C Runoff			
ARI	1	2	10	50
QUDM Factor	0.8	0.85	1	1.15
C_{ARI}	0.70	0.75	0.88	1.01

Catchment Area *A* = 3,500 m^2 (0.35ha)

Rainfall Intensities

t_c = 5 mins

I_1 = 114 mm/hr

I_{50} = 303 mm/hr

Rational Method

Q = *CIA/360*

$Q_{1yr\ ARI}$ = 0.078 m^3/s

$Q_{50yr\ ARI}$ = 0.298 m^3/s

Maximum Infiltration Rate

The maximum infiltration rate (Q_{max}) through the sand filter is computed using Equation 8.1:

$$Q_{max} = K_{sat} \cdot A \cdot \frac{h_{max} + d}{d} \qquad = 0.04\ m^3/s$$

where *K* is the hydraulic conductivity of coarse sand = 3600 m/s (Engineers Australia 2003)

A is the surface area of the sand filter = 30 m^2

h_{max} is the depth of pondage above the sand filter = 0.2 m

d is the depth of the sand filter = 0.6 m

Summary of Design Flows:

Q_1 = 0.078 m^3/s

Q_{50} = 0.298 m^3/s

Maximum Infiltration Rate = 0.04 m^3/s

8.7.3 Step 3: Design Sedimentation Chamber

The sedimentation chamber is to be sized to remove the 125 μm particles for the peak 1 year ARI flow.

Pollutant removal is estimated using Equation 4.1 (see Chapter 4):

$$R = 1 - \left[1 + \frac{1}{n} \cdot \frac{v_s}{Q/A} \cdot \frac{(d_e + d_p)}{(d_e + d^*)}\right]^{-n}$$

A notional aspect ratio of 1 (W) to 2 (L) is adopted. From Figure 4.4 in Chapter 4 (reproduced below as Figure 8-2), the hydraulic efficiency (λ) is estimated to be 0.3. The turbulence factor (*n*) is computed from Equation 4.2 to be 1.4.

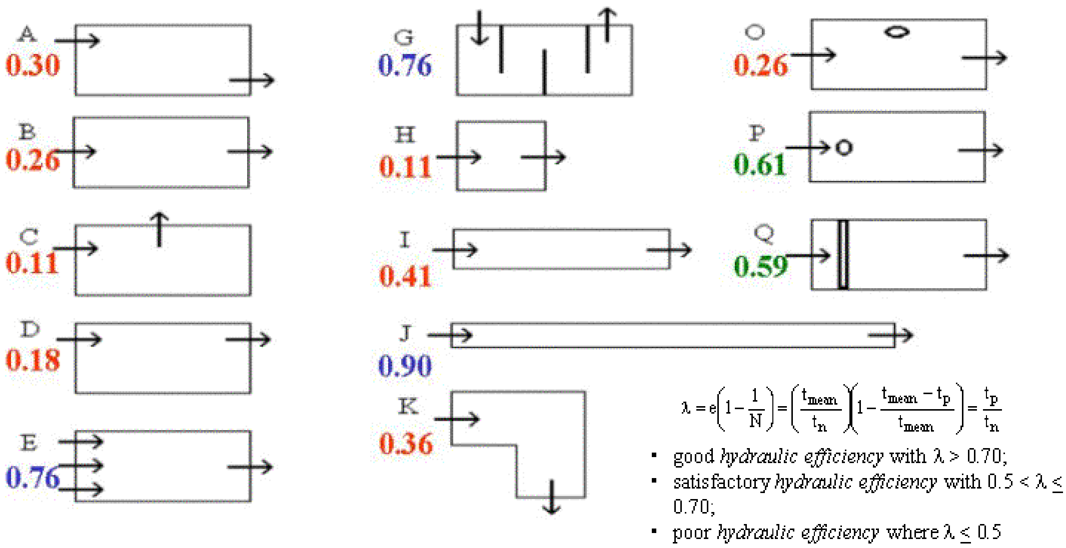


Figure 8-2: Hydraulic Efficiency (λ) Ranges (Figure 4-5 reproduced from Chapter 4).

Hydraulic efficiency (λ) = 0.3

Turbulence factor (*n*) = 1.4

The proposed extended detention depth of the basin is 0.2 m and a notional permanent pool depth of 0.6 m (equal to the depth of the sand filter) has been adopted:

d_p = 0.6 m

d^* = 0.6 m

d_e = 0.20 m

v_s = 0.011 m/s for 125 μm particles (settling velocity)

Q = Design flow rate = 0.078 m^3/s

The required sedimentation basin area to achieve target sediment (125 μm) capture efficiency of 70% is 14 m^2. With a W to L ratio of 1:2, the notional dimensions of the basin are 3 m x 4.7 m = 14 m^2. Baffles should be incorporated into the sedimentation to improve its hydraulic efficiency and, subsequently, the sediment removal efficiency. The proposed configuration, however, does still achieve the target sediment capture efficiency of 70%.

The available sediment storage (V_s) is 14 x 0.6 = 8.4 m^3. Cleanout is to be scheduled when the storage is half full. Using a sediment discharge rate (Q_{sed}) of 1 m^3/Ha/yr (Engineers Australia 2003) and a catchment area (A_c) of 0.35 ha, we have:

Frequency of basin de-silting $= \dfrac{50\% \times V_s}{A_c x\, Q_{sed} \times \text{capture efficiency}}$

$$= \frac{0.5 \times 9.9}{0.35 \times 1 \times 0.7} = 17.1 \text{ years} > 1 \text{ year} \rightarrow \text{OK}$$

During the 50 year ARI storm, peak discharge through the sedimentation chamber will be 0.298 m^3/s with flow depth of 0.8 m and a chamber width of 3 m. It is necessary to check that flow velocity does not re-suspend deposited sediment of 125 μm or larger (< 0.5 m/s).

The mean velocity in the chamber is calculated as follows:

v_{50} = 0.298/(3 x 0.8) = 0.13 m/s $\rightarrow$ OK (< 0.5 m/s).

The weir connection between the sedimentation chamber and the sand filter chamber should have a discharge capacity greater than the Maximum Infiltration Rate (= 0.04 m^3/s) and can be calculated using Equation 8.4 as follows:

$$Q_{conn} = C_w \cdot L \cdot h^{3/2}$$

where Q_{conn} = flow rate through connection (m^3/s)

C_w = weir coefficient (assume = 1.7 for a broad crested weir)

h = depth of water above the weir = 0.2 m (extended detention in sedimentation chamber)

L = length of the weir (m)

The discharge capacity calculated from the above equation for a weir length of 0.3m is 0.045 m^3/s > 0.04 m^3/s $\rightarrow$ OK. (suggestion: creating 3 of 0.1m wide “slots” @ 1m spacings to assist even distribution of flows onto the surface of the sand filter media)

Final Sedimentation Chamber Specifications:

Sedimentation Chamber Plan Area= 14 m^2

Width = 3 m; Length = 4.7 m

Total weir length for connection to sand filter chamber (minimum) = 0.3 m (provided as three 0.1 m wide “slots”)

Depth of chamber invert below weir crest = 0.6 m

Depth of Extended Detention (d_e) = 0.2m

To ensure the sediment chamber does not remain wet between rainfall events, one or more weep holes are to be provided at the base of the overflow weir to allow the sediment chamber to slowly drain to the overflow bypass chamber. This will allow the sediment chamber to free drain following an event. This will reduce the risk of odour and reduce maintenance costs associated with removing wet material.

8.7.3.1 Sand Filter Chamber

Dimensions

With the length of sedimentation chamber being 4.7 m, the dimension of the sand filter chamber is determined to be 4.7 m x 6.5 m, giving the required treatment area of approximately 30 m^2 (i.e. matches the treatment area provided for in the concept design layout).

8.7.4 Step 4: Specify Filter Media Characteristics

Sand filter layer is to consist of sand/ coarse sand material with a typical particle size distribution as provided below:

% passing	1.4 mm	100 %
	1.0 mm	80 %
	0.7 mm	44 %
	0.5 mm	8.4 %

It is expected that a sand filter media with this particle size distribution will have a saturated hydraulic conductivity in the order 3600mm/hr.

Drainage layer to be 200 mm deep and consist of 5 mm gravel.

8.7.5 Step 5: Under-drain Design

8.7.5.1 Perforations inflow check

The following are the characteristics of the selected slotted pipe:

- clear openings = 2100 mm^2/m
- slot width = 1.5 mm
- slot length = 7.5 mm
- no. rows = 4
- diameter of pipe = 100 mm

For a perforated pipe, the total number of slots = 2100/(1.5 x 7.5) = 186 per metre.

Discharge capacity of each slot can be calculated using the orifice flow equation (Equation 8.2):

$$Q_{perf} = C_d \cdot A \cdot \sqrt{2 \cdot g \cdot h}$$

where Q_{perf} = flow through perforations (2.67 x 10^{-5} m^3/s)

h = hydraulic head above the slotted pipe (0.80 m)

C_d = orifice discharge coefficient (~0.6)

The inflow capacity of the slotted pipe is thus 2.67 x 10^{-5} x 186 ~ 5 x 10^{-3} m^3/s/m-length.

Adopt a blockage factor of 0.5 giving the inlet capacity of each slotted pipe to be 2.5 x 10^{-3} m^3/s/m-length.

Maximum infiltration rate is 0.04m^3/s.

The minimum length of slotted pipe required is $L_{slotted\ pipe}$ = 0.04/2.5x10^{-3} = 16 m

With a maximum spacing of 1.5 m centre to centre, this equates to 4 lengths of 4.7 m at 1.5 m spacing (0.75 m from the edges). Therefore a total pipe length of 19 m is used. The total flow through the perforations can now be calculated:

Q_{perf} = 19m x 2.5 x 10^{-3} m^3/s/m

= 0.048 m^3/s

Check total flow through perforations 0.048 m^3/s > max flow through filtration media 0.04 m^3/s → OK

Four (4) 100 mm diameter slotted pipes (4.7 m lengths each) at 1.5 m spacing are required.

8.7.5.2 Perforated Pipe Capacity

The diameter of the slotted pipe is 100 mm. The discharge capacity of the collection pipe is calculated using an orifice flow equation (Equation 8.3):

$$Q_{pipe} = C_d \cdot A_{pipe} \sqrt{2 \cdot g \cdot h}$$

where Q_{pipe} = flow through pipe(s) = (0.019 m^3/s)

C_d = orifice discharge coefficient (~0.6)

A = area of the pipe(s) (4 pipes x 0.00785 m^2 per pipe)

g = gravity (9.81 m/s^2)

h = depth of water over the collection pipe (0.8 m)

Total discharge capacity (4 pipes) = 0.07 m^3/s > maximum infiltration rate of 0.04 m^3/s → OK

Combined slotted pipe discharge capacity = 0.07 m^3/s which exceeds the maximum infiltration rate.

8.7.6 Step 7: Size Overflow Weir

The width of the sedimentation chamber has been selected to be 3 m. An overflow weir set at 0.8 m from the base of the sedimentation chamber (or 0.2 m above the surface of the sand filter) of 2.5 m length needs to convey flows up to the 50 year ARI peak discharging into the overflow chamber.

Calculate the depth of water above the weir resulting from conveying the 50 year ARI peak discharge through a 2.5 m length weir by rearranging Equation 8.4:

$$h = \left(\frac{Q_{weir}}{C_w \cdot L} \right)^{2/3} = 0.151 \text{ m, say } 0.16 \text{ m}$$

where Q_{weir} > design discharge (0.298 m^3/s)

C_w = weir coefficient (~1.7)

L = length of the weir (m) = 3m

h = depth of water above the weir (m)

With a depth above the weir of 0.20 m, the discharge capacity of the overflow weir is 0.32 m^3/s > 50-year ARI peak flow of 0.298 m^3/s.

Crest of overflow weir = 0.2 m above surface of sand filter

Length of overflow weir = 3 m

50 year ARI weir flow depth = 0.16 m

Roof of facility is to be at least 0.36 m above the surface of the sand filter.

8.7.7 Design Calculation Summary

The table below shows the calculation summary for the worked example.

SAND FILTER DESIGN CALCULATION SUMMARY					
		CALCULATION SUMMARY			
	Calculation Task	Outcome		Check	
	Catchment Characteristics				
	Catchment area	0.35	ha	✓	
	Catchment landuse (i.e. residential, commercial etc.)	0.9 impervious			
	Storm event entering inlet	50	yr ARI		
	Conceptual Design				
	Sand filter area	30	m^2	✓	
	Filter media saturated hydraulic conductivity	3600	mm/hr		
	Extended detention depth	0.2	mm		
1	**Confirm Treatment Performance of Concept Design**				
	Sand filter area to achieve water quality objectives				
	Total suspended solids	63	% of catchment	✓	
	Total phosphorus	36	% of catchment		
	Total nitrogen	27	% of catchment		
	Sand filter area	30	m^2	✓	
	Extended detention depth	0.2	m		
2	**Determine design flows**				
	'Sedimentation chamber design flow' (1 year ARI)	1	year ARI		
	'Sedimentation chamber above design flow' (2-50 year ARI)	50	year ARI		
	Time of concentration	5	minutes	✓	
	(Refer to local Council's Development Guidelines/ QUDM)				
	Identify rainfall intensities				
	'Sedimentation chamber design flow' - $I_{1\ year\ ARI}$	114	mm/hr	✓	
	'Sedimentation chamber above design flow' - $I_{50\ year\ ARI}$	303	mm/hr		
	Design runoff coefficient				
	'Sedimentation chamber design flow' - $C_{1\ year\ ARI}$	0.70		✓	
	'Sedimentation chamber above design flow' - $C_{50\ year\ ARI}$	1.01			
	Peak design flows				
	'Sedimentation chamber design flow' - 1 year ARI	0.078	m^3/s	✓	
	'Sedimentation chamber above design flow' –50 year ARI	0.298	m^3/s		
	Q_{max}	0.04	m^3/s		
3	**Design sedimentation chamber**				
	Required surface area?	14	m^2	✓	
	length x width	3.0 x 4.7	m		
	depth	0.6	m		
	Design particle size	0.125	mm		
	CHECK SCOUR VELOCITY (<0.5 m/s)?	0.13	m/s		
	CHECK OVERFLOW CAPACITY?	0.32	m^3/s		
4	**Specify sand filter media characteristics**				
	Filter media hydraulic conductivity	3600	mm/hr	✓	
	Filter media depth	0.6	mm		
	Drainage layer depth	0.2	mm		
	Provided specification for sand media?	Yes			
5	**Under-drain design and capacity checks**				
	Flow capacity of filter media	0.04	m^3/s	✓	

SAND FILTER DESIGN CALCULATION SUMMARY					
		CALCULATION SUMMARY			
	Calculation Task		Outcome		Check
	Perforations inflow check				
		Pipe diameter	100	mm	✓
		Number of pipes	4		
		Capacity of perforations	0.048	m^3/s	
		CHECK PERFORATION CAPACITY > FILTER MEDIA CAPACITY	Yes		
	Perforated pipe capacity				
		Pipe capacity	0.07	m^3/s	✓
		CHECK PIPE CAPACITY > FILTER MEDIA CAPACITY	Yes		
6	Size overflow weir				
		Design storm for overflow (e.g. 2yr ARI)	50 Year		✓
		weir length	3	m	

8.7.8 Worked Example Drawings

The drawing at the end of the chapter details the layout of the sand filter designed in the worked example.

8.8 References

ARC (Auckland Regional Council) 2003, *Stormwater management devices: Design guidelines manual*, ARC, New Zealand

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